AUTONOMOUS SPACEBORNE FIRE DETECTION

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ABSTRACT

Current space-borne sensor systems can be used to generate products of fire susceptibility using time-series of vegetation state, the occurrence and rough location of active fires using middle and thermal infrared sensors and smoke and area burned using visible, near and middle infrared sensors.

The existing and planned operational space-borne sensors are not developed for hot event recognition and show serious limitations if geophysical parameters has to be obtained, (partly channel saturation, spatial resolution > 1 km).

Over the last five years there have been a remarkable number of initiatives in Europe and in the United States to develop dedicated satellite systems for fire detection and monitoring.

Starting from the Fire Recognition System (FIRES) Phase A Study German Aerospace Center (DLR) and OHB-System proposed a new approach to the design of autonomous satellite remote sensing systems. The simultaneous co-registration of a combination of Infrared (IR) and visible (VIS) channels is the key for a reliable autonomous on-board detection of High Temperature Events (HTE) on Earth surface, such as vegetation fires and volcano eruptions.

A Bi-spectral IR Detection (BIRD) small satellite mission is now running in a progressed instrument and spacecraft development phase at DLR, which is now supported by OHB-Systems. It will be piggyback launched in 2000 or 2001. The BIRD data will play a key role for FOCUS and for the preparation of the first generation of dedicated operational High Temperature Environmental Disaster Recognition Systems.

DLR proposed in 1997 to use the International Space Station (ISS) in its early utilisation phase as a platform and test-bed for an Intelligent Infrared Sensor prototype FOCUS of a future Environmental Disaster Recognition Satellite System. FOCUS, which is now pre-selected by ESA to be flown as an early external payload prototype on the International Space Station, has to demonstrate the reliable and near real-time on-board autonomous hot spot detection. A FOCUS feasibility study for ESA has been conducted by OHB-system, Carl Zeiss and DLR since October 1998.

Keywords: hot events on earth, forest fires, fire recognition from space, detection algorithms

INTRODUCTION

Satellite fire detection and monitoring observations are currently in an experimental or pre-operational phase and directed to the development and testing of fire detection and analysis algorithms.

The Mid Infra-Red (MIR) spectral range at 3 – 5 µm is commonly recognised as the optimal spectral range for satellite fire detection (e.g. *Robinson, 1991*), since:

- the MIR is near to the spectral maximum of fire emission,
- both, reflected solar radiation and background thermal emission are relatively low in the MIR.

As a result, the maximal fire / background contrast is achieved in the MIR. In the Thermal Infra-Red (TIR) spectral range at 8 - 12 µm the contrast is lower due to lower fire radiance and to higher background emission. In the Short Wave Infra-Red (SWIR) at 2 – 2.5 µm, where the fire radiance is also high, a serious problem for daytime hot spot observations are sun light reflections.

The main problems for reliable fire detection and analyses in satellite data are:

- strong temporal and spatial variability within the fire,
- a big dynamic range is required to avoid saturation,
- obscuration by smoke,
- variable background,
- false alarms.

There are serious limitations of existing meteorological satellite sensors used so far for the fire product generation (e.g. partly channel saturation with worse high temperature event discrimination, spatial resolution worse than 1 km) if accurate geophysical parameters have to be obtained.

The Global Change research community expects new and dedicated space-borne sensors with the resolution of 50-100 m for local and a few hundred meters resolution for global observations providing quantitative measurements of parameters like accurate geo-location (accuracy better than 0.5km), surface extent, and intensity of fire events, the frequency of their occurrence, and associated aerosol and trace gas emissions (J. S. Levine, 1996).

Administrative users of high temperature event information such as fire departments, local authorities / environmental agencies, management of forests and national parks need near real-time transmission of hot event parameters including co-ordinates at a possibly earliest stage of their development. The same is valid for potential commercial users like the management of coal mines or insurance companies.

THE STATE OF THE ART IN SPACEBORNE FIRE DETECTION

Most of the known "spaceborne" fire detection algorithms have been developed based on experience of processing the Advanced Very High Resolution Radiometer (AVHRR) data. They include the following typical procedures (e.g. Kaufman et al., 1990; Kennedy et al., 1994; Franca et al, 1995; Arino and Melinotte, 1997):

- thresholding of MIR radiant temperature T_{MIR} to retrieve potential hot spots,
- using the difference of the MIR and TIR radiant temperatures T_{MIR} - T_{TIR} to filter out warm surfaces,
- thresholding of the TIR radiant temperature T_{TIR} to filter out clouds,
- using VIS/NIR channels to filter out high-reflection surfaces.

However, the MIR threshold values used for the MIR channel data of the NOAA-Satellites AVHRR and the ERS 1 & 2 Satellite Along Track Scanning Radiometer (ATSR) are „fixed" to figures corresponding to the saturation limit of these sensors. This is the only way to proceed, but it is far from the optimum. Optimised hot spot detection algorithms must be implemented and validated as soon as new spaceborne sensor data will be available not suffering from the saturation of their MIR channel.

NEW SPACEBORNE SENSORS FOR FIRE RECOGNITION

The ***Moderate Resolution Imaging Spectrometer (MODIS)*** with a MIR channel which will be saturated at 450 K will be launched on board of the ***EOS satellite AM1 "Terra"*** in 1999. The on-ground pixel size of this channel and of most of the other MODIS channels at nadir will be ~ 1 km.

Starting from the *FIRES Study*, the DLR develops a new approach to the design of a small satellite mission for ***Bi-spectral IR Detection (BIRD)*** which is dedicated to hot spot detection and evaluation. The BIRD project is running in phase C since September 1997. The BIRD sensor system consists of:

- a push-broom Hot Spot Recognition Sensor (HSRS) with adaptive saturation levels in the MIR and TIR channels (*Lorenz et al., 1997*) and

- a wide-angle Optoelectronics Stereo Scanner (WAOSS), originally developed for the Mars ’96 mission.

Two options are considered now for piggyback launch of the BIRD satellite:

1. Launch in first half of 2000 together with the German satellite CHAMP into a non sun-synchronous circular orbit.

2. Launch in second half of 2000 or in 2001 on an Indian Rocket (together with other S/C) into a sun-synchronous orbit.

An airborne model of the BIRD sensors has been flown successfully since 1997.

DLR submitted in 1997 to the European Space Agency (ESA) a proposal for a ***High Temperature Environmental Disaster Recognition System Prototype FOCUS*** to be flown as an Externally mounted Payload during the Early Utilisation Phase of the International Space Station (ISS). One of the main goals of this experiment is the realisation and validation of the autonomous on-board recognition of high temperature events. The Intelligent Infrared Sensor System FOCUS was peer review evaluated and selected by ESA as the European Earth Observation payload grouping for the early utilisation phase of the Space Station. The nine month FOCUS Phase A Feasibility Study was successfully completed in July 1999.

FOCUS is a prototype mission combining a number of proven technologies and observation techniques to provide the scientific and operational user community with key data for the classification and monitoring of forest fires and of volcano activities by means of its innovative technology features:

- a forward looking imaging IR sensor with direct link to a processor dedicated for near real-time on-board autonomous seeking, detection and selection of hot spots, and

- a high resolution IR-spectrometer / IR-imager sensor combination for remote sensing of the hot event gas emissions allowing to estimate the burning efficiency and the emission factors of vegetation fires as well as volcanic gas emissions.

HOT SPOT DETECTION TESTS FOR NEW SPACEBORNE SENSORS

Development of new hot spot detection algorithms - in preparation of the BIRD and FOCUS missions - was based on simulations and on processing of airborne fire images.
Using a surface/ atmosphere/ sensor model, a *testing set* has been developed for testing and optimisation of fire detection algorithms that includes the following objects:

a) fires with:

- the equivalent temperature of 500, 800 and 1500 K,

- the equivalent relative pixel area q of from 0 to 1;

- cool green and burned within-pixel background (fire G and fire B respectively),

- smoke coverage of 0 and 1;

b) diffuse objects occupying the entire pixel, with temperatures of 0, 5, 10, 15, and 20 K above the background;
c) sun glints on water, on glass and metallic roofs, and on icy clouds with the relative pixel area of 0 to 1 and with temperatures of 0, 5, 10, 15, and 20 K above the background;
d) the standard MODTRAN clouds (without sun glints) and fogs.

Experimental data were obtained with the 79 channel Digital Airborne Imaging Spectrometer (DAIS 7915) that was operated over artificial fires. DAIS 7915 covers the spectral range from VIS (0.45 µm) to TIR (13 µm) including a MIR (3 – 5 µm) channel. The ground resolution of all 79 co-registered channels is 10 m from 3 km altitude above ground level. As a result of modelling / simulation work and of the processing of these artificial airborne fire images, the following tests for **detection and analysis of High Temperature Event (HTE) by new spaceborne sensors** has been proposed and tested:

- *Geographical false alarm rejection***.** This step excludes from processing the areas, where the HTE’s can not be expected (e.g. large water bodies), as well as the known industrial hot spots. It requires an accurate data geo-referencing.

- *Bright spot detection.* This step allows to select bright spots in the MIR images by an adaptive MIR thresholding (*FIRES, 1994*).

- *Preliminary rejection of false alarms.* This step includes the following three tests to reject most of the false alarms:
  - *Absolute TIR thresholding to reject clouds.* Since clouds have a low temperature, a rather low TIR threshold may be sufficient for this purpose.

  - *Thresholding of the MIR/VIS radiance ratio.* This test allows to reject high reflecting surfaces. The MIR/VIS ratio threshold value of $thresh_{MIR/VIS} = 0.01$ was found to be optimal for the investigated scenes.

  - *Adaptive TIR thresholding.* The adaptive TIR thresholding allows to select among the MIR bright spots only those pixels, which have the TIR radiance value higher than for the background. A rather small TIR threshold, corresponding to ~1 K above the median value, can be recommended to be used for this purpose in order not to limit the detectability of small HTE's.

  - *Application of the Bi-channel Technique (Dozier, 1981).* The Bi-channel Technique is applied to the MIR and TIR signals of the pixels, which have been selected after the preliminary false alarm rejection, to retrieve the apparent target temperature and the apparent target area. Thresholding of the target temperature is the final step in the false alarm rejection.

Figure 1 illustrates the application of the proposed new fire detection algorithm to an artificial straw-fires image obtained by the Digital Airborne Imaging Spectrometer DAIS-7915 on-board a Do-228 aircraft from the altitude of 3 km above the ground level. The used artificial fire scene contained a compact group of four straw fires with the following sizes:

- three rectangular small fires of: 1.2 x 1.0 m^2, 1.2 x 2.0 m^2, and 0.8 x 1.0 m^2, and

- a larger fire "cross" of two 7.0 x 0.8 m^2 stripes.

AUTONOMOUS DETECTION

The **on-board real time autonomous hot spot detection** is one of the main objectives of the FOCUS experiment on ISS. A FOCUS Fore Field Sensor (FFS) and a real-time processor are considered to achieve this challenging goal.

An autonomous fire detection algorithm has been successfully developed, simulated and computer tested during the FOCUS Phase A Study in 1999. It includes the outlined hot spot detection tests, auxiliary operations (data correction and co-registration, geo-referencing and adaptation of the algorithm parameters using the navigational data) as well as selection of a target for detailed observations by the Main Sensor. Its feasibility for implementation on available space-qualified processors has been demonstrated.

OUTLOOK

FOCUS will allow to compare within field experiments the fire recognition capability of advanced spaceborne fire detection sensors, airborne and ground based forest fire surveillance/ alert systems (manned and automated towers).

FOCUS as a scientific and technological demonstrator/ precursor of an operational fire observation system shall be implemented by the first flight opportunity for the early externally mounted European payloads of ISS.

ESA and NASA consider FOCUS as a co-operative Payload of the International Space Station.

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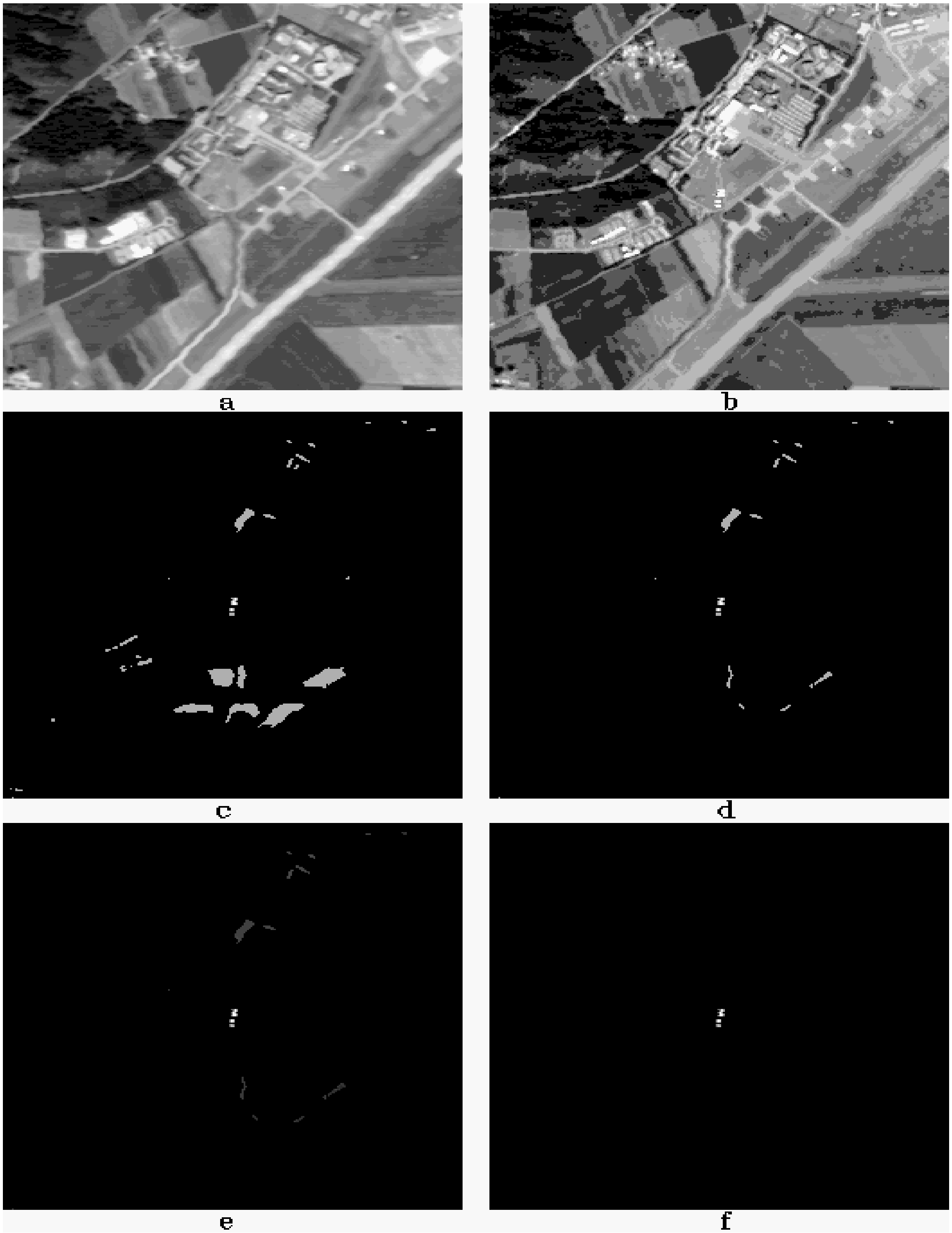

Figure 1. Application of the HTE detection-and-analysis algorithm to a DAIS-7915 straw fire scene: a - VIS image; b - MIR image; c - detected bright spots; d - bright spots after the preliminary false alarm rejection; e – sub-pixel target temperatures retrieved by the Bi-channel technique; f - detected fires after the final false alarm rejection (using temperature thresholding).

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